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NATIONAL WEATHER SERVICE RIVER FORECAST SYSTEM- SNOW ACCUMULATION AND ABLATION MODEL

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CHAPTER 1. INTRODUCTION

1.1 BACKGROUND

The techniques used by the National Weather Service (NWS) for making river and flood forecasts have been changing in recent years (Sittner, 1973). Conceptual watershed models are replacing previously used empirical procedures. In 1972 the Hydrologic Research Laboratory of the Office of Hydrology, NWS, prepared a technical memorandum entitled "National Weather Service River Forecast System, Forecast Procedures" (referred to as HYDRO-14 throughout this report) as a guide for the implementation of conceptual river forecasting models by field offices. HYDRO-14 describes the techniques and computer programs needed for developing operational river forecasts based on the use of a continuous conceptual watershed model from the processing of the basic data to the preparation of the forecasts. The procedures described in HYDRO-14 did not include techniques to model snow accumulation and snowmelt. This Technical Memorandum describes a conceptual model of the snow accumulation and ablation process and the associated computer subroutines and programs which enable the model to be used in conjunction with the National Weather Service River Forecast System (NWSRFS). Guidelines and methods for determining model parameter values for a given area are also presented. Even though the snow subroutines are written for use with the NWSRFS, the snow accumulation and ablation model itself can be used with almost any soil-moisture accounting (rainfall-runoff relationship) and channel routing procedure. The output from the snow model would be the input to the soil-moisture accounting procedure. The output from the snow model is snowpack outflow (snowmelt water and rainwater leaving the snowpack) plus rain that fell on bare ground.

1.2 DATA REQUIREMENTS

The snow accumulation and ablation model uses air temperature as the sole index to energy exchange across the snow-air interface. Air temperature is the only additional data needed to use the snow model in conjunction with the NWSRFS soil-moisture accounting and channel routing models. Streamflow, precipitation, and some form of potential evapotranspiration (PE) data are needed for the NWSRFS (see chapter 2, HYDRO-14). The basic computational interval of the NWSRFS is six hours, thus, six-hourly mean areal air temperature data are required. Chapter 2 of this Technical Memorandum describes a procedure and associated computer programs for computing six-hourly mean areal air temperature from daily maximum-minimum air temperature observations. Since the NWSRFS models and the snow model are continuous models, a continuous record of six-hourly mean areal air temperature data is required. However, the snow subroutines contain a provision that eliminates the requirement for valid air temperature data during periods when there is no snow on the ground.

There are two basic reasons for using air temperature as the sole index to energy exchange across the snow-air interface:

a. Air temperature data are readily available throughout the United States on a real time operational basis.

b. Comparison tests conducted by the Hydrologic Research Laboratory have shown that on two experimental watersheds the temperature index method of estimating energy exchange across the snow-air interface has produced simulation results which are at least as good as those produced using a combination energy balance - aerodynamic method. The combination energy balance - aerodynamic method tested is essentially the same as the method described by Anderson (1968). The two watersheds on which these tests were made are Upper Castle Creek, Central Sierra Snow Laboratory, and Watershed W-3, Agricultural Research Service (ARS), Sleepers River Research Watershed.

The combination method will give more accurate estimates of energy exchange at a point than the temperature index method if accurate measurements of all the necessary meteorological variables are available (these variables are air temperature, dew-point, wind speed, incoming and reflected solar radiation, and atmospheric longwave radiation). However, on the two experimental watersheds the combination method results were affected by several sources of error: 1) errors in point measurements, especially in regard to incoming solar radiation, 2) errors in estimating variables which were not measured (primarily atmospheric longwave radiation), and 3) errors in estimating mean areal values of the variables (primarily determining the effect of slope, aspect, and forest cover on incoming solar and atmospheric longwave radiation, determining the areal albedo of the snowpack, and determining the mean areal wind speed). The integrated effect of these errors was estimates of energy-exchange across the snow-air interface which were no better than estimates from the temperature index method on the two experimental watersheds.

It is felt that the data available at these two experimental watersheds is superior to that which is generally available on a real-time operational basis in the United States. Thus, it does not appear practicable to use a physical energy balance approach like the combination method to estimate energy exchange across the snow air interface until improved measurements of the meteorological variables affecting snowpack energy exchange are obtained and until improved methods of accounting for the effects of physiographic factors on snowpack energy exchange variables are developed.

The Hydrologic Research Laboratory is currently involved in a project to obtain the highest possible quality data for the purpose of developing and testing snowpack energy exchange equations at a point. This study is the NOAA - ARS Cooperative Snow Hydrology Project on the Sleepers River Research Watershed (Johnson and Anderson, 1968). Ultimately these measurements of the variables affecting snowpack energy exchange will be used along with data from an adjacent watershed to develop improved methods of accounting for the effect of physiographic factors, such as slope, aspect, elevation, and forest cover on the mean areal values of the meteorological variables.

Air temperature is a very good index to snowpack energy exchange in a dense coniferous forest. The only energy exchange mechanism showing much variability is longwave radiation exchange, which is a function of the difference between canopy temperature and snow surface temperature. Canopy temperature is closely related to air temperature. The other primary energy exchange mechanisms, shortwave radiation exchange, sensible heat exchange, and latent heat exchange show very little variability because there is only a slight amount of solar radiation penetrating the forest canopy and because wind movement is limited. On the other hand, in an open area there generally is a large amount of variability in solar radiation exchange, longwave radiation exchange, sensible heat exchange, and latent heat exchange. Because of this variability, air temperature is not nearly as good an index to snowpack energy exchange in an open area. Therefore, there is a greater potential for improvement in estimating snowpack energy exchange by using a physical energy balance method, rather than a temperature index method, in areas where the values of the variables affecting energy transfer can exhibit large variations. It is felt that in the near future when accurate measurements of the variables affecting snowpack energy exchange are available and when techniques of accounting for the areal variability of the variables are improved that physical energy balance equations will provide a more accurate estimate of the energy exchange across the snow-air interface.

In regard to the data period required for model parameter calibration, the recommendation given in HYDRO-14 is generally applicable to watersheds where snow is included. HYDRO-14 indicates that it is desirable to sample each mathematical relationship in the model over its maximum possible range; thus, a long data period is indicated. However, in many cases watershed characteristics change with time. For river forecasting we are interested in parameters which express the near future. Since the future cannot be sampled, a short record representing the immediate past is the second choice. Based on these considerations, HYDRO-14 recommends that "A suitable compromise seems to be the most recent 10 years of record.". For most watersheds, 10 years of record is completely adequate for determining model parameter values. However, in arid or semi-arid areas and in areas where significant snowpacks do not accumulate every year, more than 10 years of data may be required to determine adequately all the model parameters. In areas with considerable hydrologic activity and where large snowpacks accumulate every winter, less than 10 years of data may be sufficient to determine model parameter values.

1.3 TEST WATERSHEDS AND RESULTS

This Technical Memorandum does not present detailed results of tests of the snow accumulation and ablation model. However, for the benefit of potential users it is felt that a listing of the watersheds tested to date and a brief summary of the simulation results on these watersheds might be informative. Table 1-1 lists the watersheds tested and presents several statistics which summarize the comparison between observed and simulated mean daily discharge. Data from the Central Sierra Snow Laboratory were used for testing various mathematical formulations during the development stage of the snow model. The estimation of energy exchange when air temperature is below 32°F was modified based on tests using data from Sleepers River Watershed W-3. The other watersheds were used to test the applicability of the model to different size areas and to different physiographic and climatic conditions.

1.4 COMPUTER PROGRAMS AND COMPUTER REQUIREMENTS

There are three basic computer programs in the NWSRFS which include the snow accumulation and ablation model. These are: 1) the verification program (NWSRFS4) which is used to check the simulation accuracy of various sets of parameter values, 2) the optimization program (NWSRFS3) which is used to determine parameter values by an automatic optimization technique, and 3) the operational river forecasting program (NWSRFS5) which is used to prepare river discharge forecasts on an operational basis. The NWSRFS also contains a number of data processing programs (see chapter 3 of HYDRO-14). Chapter 2 of this Technical Memorandum describes three additional data processing programs for use in computing mean areal air temperature. These are: 1) the basic mean areal air temperature program (MAT Program), 2) the MAT consistency check program (Program MATCØN) which checks the consistency of each station used in the mean areal temperature analysis, and 3) the MAT temperature check program (Program TEMPCK) which compares the estimated and observed maximum and minimum temperatures at a given air temperature observation station. Table 1-2 lists the program dimensions, storage requirements, and typical run times for the six programs involving the snow accumulation and ablation model and the computation of mean areal air temperature. The programs are written in FØRTRAN IV for use on a CDC 6600 computer system. Minor revisions may be necessary for use on other computer systems.

The computer programs and test data sets described in HYDRO-14 are available on magnetic tape from:

Acquisition Office
National Technical Information Service
U. S. Department of Commerce
Springfield, Virginia 22151

Accession number: COM 73-10298
Cost: $97.50

These programs contain all the necessary statements for use with the snow subroutines (One exception; a few changes were made to Program NWSRFS5 after preparation of the magnetic tape. The changes are only needed when the snow model is included. Appendix H lists these changes to Program NWSRFS5). Information on how to obtain the snow subroutines for programs NWSRFS3, NWSRFS4, and NWSRFS5, plus the programs for the computation of mean areal air temperature can be obtained from:

Hydrologic Research Laboratory, W23
Office of Hydrology
National Weather Service, NOAA
Silver Spring, Maryland 20910

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Staff, Hydrologic Research Laboratory, "National Weather Service River Forecast System, Forecast Procedures", NOAA Technical Memorandum NWS HYDRO-14, U. S. Department of Commerce, Silver Spring, Md., December 1972.

Table 1-1.--Summary of simulation results on the watersheds tested with the snow accumulation and ablation model in conjunction with the NWSRFS as of June 1973.

Watershed	Data Period	Area mi^2	Elev. Range[1]	Number of Stations				Mean Annual Runoff Inches and CFSD	RMS Error CFSD	Correl. Coef.	% Bias	Best Fit Line Obs.=a+b·Sim.	
				Precip	Elev. Range	Air Temp.	Elev. Range					a CFSD	b
Upper Castle Creek, Central Sierra Snow Laboratory	10/46-9/51	3.96	6880-9105 7050-8250	1	6890	1	6890	46.1" 13.5 CFSD	8.3	.971	-2.0	-0.4	1.05
Skyland Creek, Upper Columbia Snow Laboratory (UCSL)	10/46-9/50	8.1	4800-7610 5200-6800	1	4840	1	4840	31.5" 18.8 CFSD	6.7	.981	1.5	-0.3	1.0
Bear Creek, UCSL[2]	10/46-9/50	12.6	4480-8605 4900-6350	1	4840	1	4840	29.5" 45 CFSD	13.8	.983	0.2	-0.3	1.01
W-3, ARS Sleepers River Watershed	10/62-9/67	3.23	1140-2260 Unknown	3	1350-2200	1	1140	21.7" 5.2 CFSD	2.1	.955	1.6	0.2	0.95
W-8, ARS Sleepers River Watershed[2]	10/62-9/67	2.81	920-1680 Unknown	2	1150-1350	1	1140	17.2" 7.7 CFSD	2.2	.970	2.3	0.2	0.95
W-1, ARS Sleepers River Watershed[2]	10/62-9/67	10.54	740-2430 Unknown	4	1150-2200	1	1140	17.1" 20.9 CFSD	8.7	.964	3.5	-1.7	1.04

Table 1.1 (continued)

Passumpsic R. at Passumpsic, Vermont	10/63-9/71	436.	530-3400 780-2240	4	699-1140	3	699-1140	20.3" 653 CFSD	294.	.939	-1.5	49.	0.94
Rock River at Rock Rapids, Iowa	10/59-9/69	788.	1330-1950 Unknown	6	1350-1700	6	1350-1700	3.1" 179 CFSD	444.	.906	5.9	28.	0.80

1 First range is for the total area. Second range is for 90 percent of the area, excluding the upper and lower 5 percent. All elevation ranges are in feet above m.s.l.

2 Streamgage is downstream from another calibrated watershed. Local area was calibrated using observed upstream inflows. Area, elevation range, and station information are for local area only. Mean daily discharge comparisons are based on the total flow at the streamgage.

Table 1-2.--Program dimensions, storage requirements[1], and typical run times[1] for NWSRFS programs using the snow model and programs for computing mean areal air temperature.

Program	Dimensions	Storage Requirements Decimal Words	Typical Run Times
Verification Program (NWSRFS4)	5 snowpack and soil-moisture accounting areas. 5 streamflow points. 3 upstream inflow points. 2 PE stations	39K	2 sec./year for each snowpack and soil-moisture accounting area, plus 3 sec./year for each streamflow point
Optimization Program (NWSRFS3)	2 snowpack and soil-moisture accounting areas. 1 streamflow point. 4 upstream inflow points. 2 PE stations 50 months of data	32K for program, plus 75K for data storage	5.5 sec./50 months for each snowpack and soil-moisture accounting area, plus 1 sec./50 months for the streamflow point
Operational River Forecasting Program (NWSRFS5)	10 snowpack and soil-moisture accounting areas. 10 streamflow points. 5 upstream inflow points. 3 PE stations. 14 days of data.	29K To enlarge river system requires approx. 350 words/snowpack and soil-moisture accounting area, plus 600 words/streamflow point	1 sec./14 days for each streamflow point
Mean Areal Air Temperature Program (MAT Program)	40 maximum-minimum air temperature stations 10 areas to compute mean areal temperature 4800 months of data storage	37K for program, plus 744 words of random access data storage per station year	7 sec./year for an analysis involving 10 stations

Table 1-2. (continued)

MAT Consistency Check Program (Program MATCON)	40 maximum-minimum air temperature stations 5 groups for double mass analysis 25 years of record	33K for program, plus 24 words of data storage per station year (data are generated by MAT Program)	1 sec./year for an analysis involving 10 stations
Program TEMPCK		40K for program, plus 1488 words of data storage per year (data are generated by MAT Program)	0.5 sec./year

1 Storage requirements and run times are based on a CDC 6600 computer system.